Recycling gives new purpose to spent nuclear fuel

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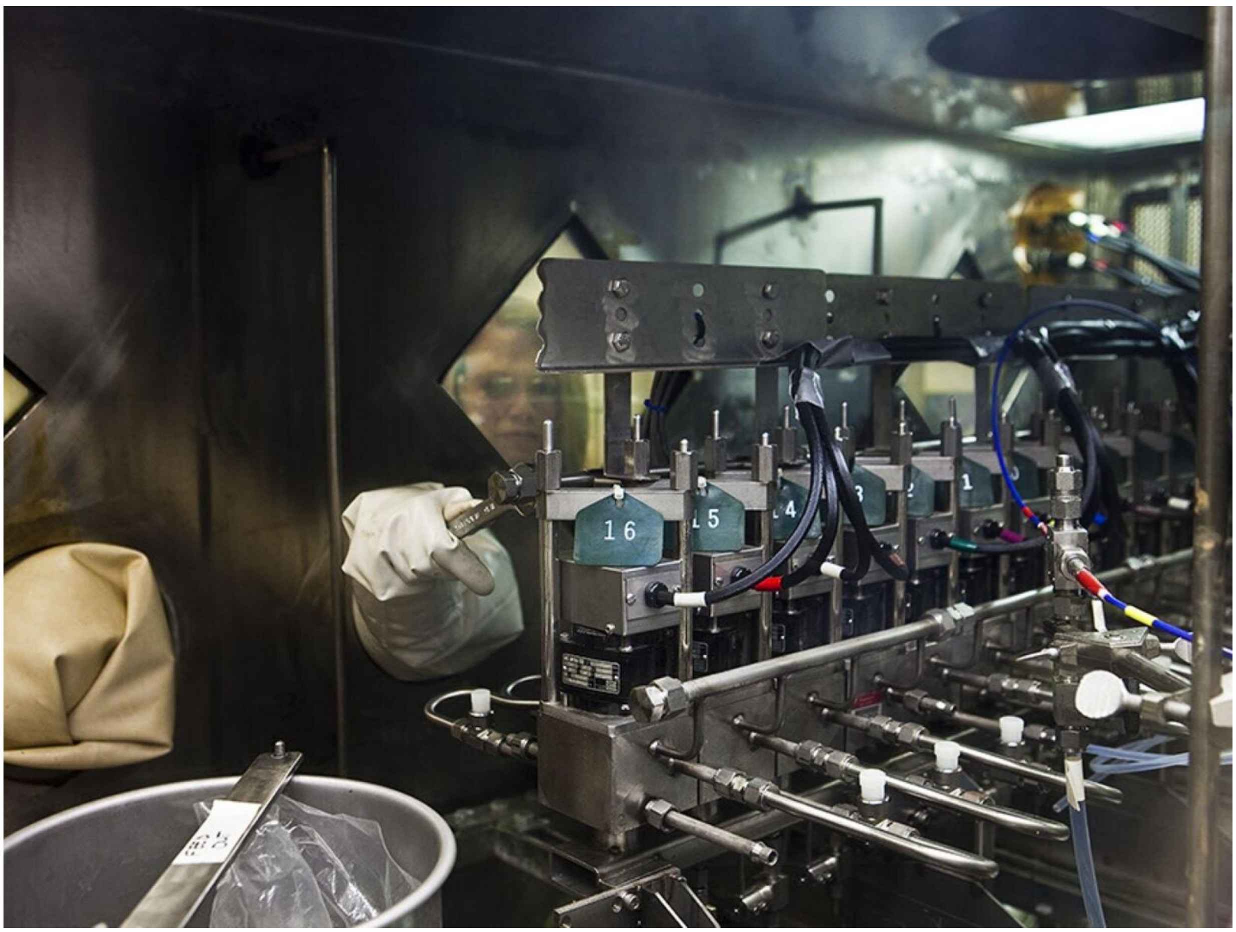

For recycling, spent nuclear fuel is fed into a chemical processing system that separates actinide elements that can be recycled as mixed-oxide fuel to produce more electrical power. At PNNL, this research is done in the Radiochemical Processing Laboratory, a Hazard Category II non-reactor nuclear research facility. Credit: Andrea Starr | Pacific Northwest National Laboratory

Imagine filling up your gas tank with 10 gallons of gas, driving just far enough to burn a half gallon and discarding the rest. Then, repeat. That is essentially the practice that the U.S. nuclear industry is following.

Spent nuclear fuel from power plants still has 95% of its potential to produce electricity. Current plans are to dispose of the spent nuclear fuel in a geologic repository. So, why is it not recycled? It turns out that separating usable versus unusable parts of spent nuclear fuel is complicated.

"Spent nuclear fuel contains roughly half of the periodic table. So, from a chemistry standpoint, there's a lot going on," said Gregg Lumetta, PNNL chemist and laboratory fellow. "And to reduce proliferation risk, it is best if pure plutonium is not produced at any point in the separation process."

Researchers from Pacific Northwest National Laboratory (PNNL) developed an innovative capability to rapidly separate, monitor, and tightly control specific uranium and plutonium ratios in real-time—an important achievement in efficiently controlling the resulting product and safeguarding nuclear material.

A spent nuclear fuel recycling twofer

With the rising demand for carbon-free power, nuclear is an option in the green-energy mix, particularly with advanced reactors on the horizon. Yet, there are still some big challenges to overcome: what happens to spent nuclear fuel that currently goes unused, and how do we power advanced reactors?

"Perhaps, these challenges have the same solution—recycling spent nuclear fuel to make new fuel," said Amanda Lines, a PNNL chemist. "In a world of increased energy demand challenged by growing carbon footprints, how can we better use spent nuclear fuel?"

New advanced reactors could be designed to run off recycled fuel. But recycling spent nuclear fuel means separating the energy-generating plutonium from everything else in the mix while not separating it in pure form, which is viewed as a proliferation risk. Also, the final product must be a precise ratio of uranium to plutonium to produce new fuel that can be reused in nuclear reactors.

Deconstructed salad dressing

Separating spent nuclear fuel is like trying to deconstruct vinaigrette salad dressing with the goal of moving ingredients from vinegar to oil.

The chemical slurry is fed into a centrifuge processing system, which looks like a giant pillbox with each compartment containing a rotor for mixing. The solution flows from one end of the system to the other, mixing, centrifuging, adding, or subtracting different chemical components along the way. Throughout the process, real-time monitoring provides critical insights into what adjustments need to be made to maintain specific chemical compositions.

"Real-time monitoring was pivotal to determining exact chemical elemental ratios. We really focused on the uranium-plutonium percentages and knew exactly what they were at any given point," said Lines.

Real-time monitoring also improves efficiency, reduces costs, and takes an established process into a more modern and futuristic realm.

"Ultimately, it empowers researchers and operators by providing nearly instantaneous information to help control and understand chemical processes," said Lines.

PNNL's real-time monitoring capabilities have exponentially evolved over the past 25 years, intersecting with a long history of fuel recycling and separations research.

From industrial to microscale

Separations researchers often rely on manmade, simulated spent nuclear fuel to mimic the chemical processes because actual spent nuclear fuel is expensive to acquire and study. However, simulated spent nuclear fuel is also costly, particularly at the large, industrial scales necessary to study bulk recycling and separations processes.

To address that challenge, PNNL has developed complementary approaches that can be done at a much smaller, and much less costly, scale. Using microfluidics, or lab-on-a-chip, technology coupled with real-time monitoring, researchers can track chemical processes on something the size of a microscope slide.

"We can run the same types of separations studies and track the exact composition of uranium fuel components and fission products throughout the recycling processes, similar to what is done at a lab or industrial scale," said Lines.

The researchers are also able to use actual spent nuclear fuel because the scale is so much smaller. "This technology is cost efficient and enables incredible opportunities to develop and advance recycling approaches," said Lines.

50+ years of spent nuclear fuel recycling and separations

From reducing the amount of radiation in high-level radioactive waste to developing a separation process to remove hazardous elements in spent fuel, PNNL has a long history solving some of the nation's toughest spent nuclear fuel challenges.

"We've been advancing fuel-cycle operations for decades," Lumetta said. "This most recent work is a platform for us to expand upon as we continue to pursue chemical separations for advanced fuel-cycle options."

More information: Gilbert L. Nelson et al. Enabling Microscale Processing: Combined Raman and Absorbance Spectroscopy for Microfluidic On-Line Monitoring, *Analytical Chemistry* (2020). DOI: 10.1021/acs.analchem.0c04225

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Provided by Pacific Northwest National Laboratory

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