

tunities to raise objections and suggest solutions. As the idea for the IBL took shape, Mainen was inspired by the nonhierarchical structure of the ATLAS collaboration, a CERN experiment with roughly 3000 participants. With around 40 members total, the IBL is much smaller, but the idea is to put governance structures in place now in preparation for it to grow, he says.

There is a large activation barrier to working as a huge group, says Princeton University's Ilana Witten, who chairs the IBL working group on publications and postdocs. An individual can work faster alone, making independent decisions. "But if we can overcome the activation barrier, the promise of standardization is that science will move more quickly. It

will lead to more results—and more reproducible results."

Another barrier is that sharing data is not part of the neuroscience culture. "It's been said neuroscientists would rather share their toothbrush than their data," says Häusser. But the science questions are an incentive to develop a pipeline for putting the data together, and that will be a win, he says. The IBL data are freely available across the consortium. "I hope we will be able to get people in the field to be more open about sharing their data."

Still, researchers are typically judged by their first-author publications, and standardizing experiments entails a tradeoff with individual creativity. Those are sociological challenges, says Mainen. "We need to show that people who work

in the IBL will be well-recognized and land good jobs. A large-scale group effort need not diminish creativity."

So far, the IBL represents perhaps 5–25% of the principal investigators' funding. It's the minimum to get started, says Mainen. The groups each have enough funding for one postdoc or graduate student. The grants also cover equipment and some travel.

Changing entrenched sociological behavior will be difficult, says Koch. "But teaming up is the way to go. It will happen. Neuroscience is no longer at the romantic phase of everyone chasing their favorite question. People want progress. People want therapy for Parkinson's, for schizophrenia."

Toni Feder

DOE prepares major upgrade of its lithium-6 operations

The isotope is used to make and sustain nuclear warheads. Recycling it from old warheads may not meet demand.

As part of its recently released nuclear posture review, the Trump administration has unveiled multibillion-dollar plans for the Department of Energy to build a uranium enrichment plant, upgrade its plutonium pit fabrication capacity, and expand tritium production. Less prominent, perhaps, is the agency's proposal to build a \$700 million plant to ensure a continuing supply of lithium-6, an equally essential ingredient in nuclear weapons' explosives.

In February Steven Erhart, the acting administrator of DOE's National Nuclear Security Administration (NNSA) at the time, lamented that the US had lost its capacity to produce lithium; he told attendees at a weapons conference that the deficit needed to be addressed "on an urgent basis" to maintain the US nuclear stockpile.

Thermonuclear warheads are multistage, with solid lithium-6 deuteride as the fusion fuel for the second stage. Neutrons released by the fissioning of plutonium in the weapon's primary stage combine with the lithium to create tritium. The tritium then fuses with the



TECHNICIANS AT THE DEPARTMENT OF ENERGY'S Y-12 National Security
Complex process lithium compounds for use in weapon components.

deuterium to yield high-energy neutrons that trigger the fission of uranium or plutonium in the secondary stage.

In addition, ^6Li is used to produce tritium gas that's released into the weapon's primary stage to boost the fission of plutonium. For that application, lithium aluminate metal is fabricated into target rods that are irradiated in a

nuclear power plant operated by the Tennessee Valley Authority. The NNSA plans to start tritium production in a second TVA reactor in 2021 (see PHYSICS TODAY, March 2018, page 29).

The DOE fiscal year 2019 budget request includes \$19 million to begin designing a replacement plant for the lithium-processing operations housed in

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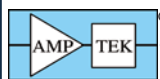
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THE CASTLE BRAVO TEST AT BIKINI ATOLL in 1954 was the first to use lithium deuteride as a thermonuclear fuel. Scientists underestimated the device's yield by a factor of two and a half due to a mistaken belief that lithium-7 would not produce tritium in a neutron flux.

a crumbling World War II-era facility at the Y-12 National Security Complex in Oak Ridge, Tennessee. Until completion of the new factory, which, subject to appropriations, is scheduled for 2026, the NNSA will continue to obtain most of the lithium it needs by recycling material from dismantled warheads.

Direct recycling alone will not be sufficient to meet the demand for ${}^6\text{Li}$, according to the NNSA. The rate of warhead dismantlement is fixed by the capacity of the weapons assembly-disassembly plant in Amarillo, Texas. There is a plentiful supply of dismantled warheads; more than 2200 were taken apart during the Obama administration, and another 2800 were in line for dismantlement, former vice president Joe Biden revealed in January 2017.

But the NNSA has withheld the secondaries of multiple retired warhead types from recycling, as noted in a 2014 Government Accountability Office report. The agency wants to retain those secondaries intact both for possible reuse in weapon refurbishment programs and as a hedge against uncertain effects of aging. The NNSA is also holding onto the secondaries of the five-megaton warhead from the short-lived Spartan missile for potential use in defending Earth against an asteroid impact, the GAO report said.

Also slowing direct recycling is a re-

quirement that the weapons laboratories assure the lithium compound from each retired system is of an adequate quality for reuse. A 2015 audit by DOE's Office of Inspector General said that 15% of lithium from dismantled warheads didn't meet purity requirements. The audit report warned that the NNSA would run out of available lithium by September 2017.

But NNSA officials now say there is sufficient ${}^6\text{Li}$ to last through 2030. The supply has been increased by "adjusting dismantlement schedules in a manner that better lines up with future demand," a spokesperson says.

Degraded infrastructure

For long-term stability, lithium is stored in the form of lithium chloride. Until the new factory is completed at Y-12, the NNSA plans to resume processing its stocks of lithium chloride that were produced before it halted lithium purification and processing operations in 2013. The agency will restart both an electrolytic cell used to reduce lithium chloride to metal and the hydriding reactors that combine the material with deuterium to form lithium deuteride.

Hazardous wet-chemistry operations that historically were used to produce lithium chloride from used ${}^6\text{LiD}$ won't be restarted. That means Y-12 will continue to be unable to eliminate contaminants from lithium scrap or powder that

doesn't meet quality standards. The wet-chemistry process involved dissolution in hydrochloric acid, which contributed to corrosion of the building's structural components and led to chunks of concrete falling from the 75-year-old ceiling.

"The greatest risks to the lithium production mission are the limited supply of usable lithium and the degraded processing equipment and infrastructure of the lithium production facility" at Y-12, an NNSA spokesperson says.

The 2013 shutdown of the processing equipment at Y-12 coincided with a tripling of demand for new lithium components, a demand created by refurbishment of three of the seven weapons systems that make up the current nuclear arsenal (see *PHYSICS TODAY*, November 2013, page 27).

The NNSA has nearly completed refurbishment of the W76 warheads that top some of the US Navy's submarine-launched ballistic missiles. The first of an estimated several hundred modernized B-61 gravity bombs is scheduled to be rolled out in 2020. And a revamp of the W80 cruise-missile warhead that will be carried on the US Air Force's planned long-range standoff missile (an updated cruise missile) is in the late planning stages. Each refurbishment program includes a refresh of the warheads' lithium components.

NNSA officials say the new plant will be more efficient and agile than the old one, which is oversized for today's needs. The agency is evaluating at least four safer, more efficient, and more reliable technology alternatives to the wet-chemistry process. The same processes could also be deployed to supplement the lithium chloride supply until the new facility is operating, they say. The agency is also weighing outsourcing parts of the lithium production process until the new plant is finished.

Direct recycling of ${}^6\text{LiD}$ from refurbished warheads is half as expensive as the wet-chemistry purification route, according to a public Y-12 document. In recycling, the lithium components from dismantled warheads are sanded and wiped to remove impurities, pulverized, and converted via cold isostatic pressing into blanks for machining into new weapon components. Lithium processing and machining operations are performed in glove boxes to prevent reactions with moisture.

Up to half of the lithium compound is

lost to dust during machining. Although the dust is captured and stored, it can't be reused without first being processed into lithium chloride, according to the GAO report. The NNSA says it is evaluating a technology for direct recycling of the dust.

A hazardous legacy

Naturally occurring lithium contains only about 7% ${}^6\text{Li}$, but weapons require enrichment up to 95% ${}^6\text{Li}$. The Atomic Energy Commission, DOE's predecessor, carried out enrichment at Y-12 from 1954 to 1963. During that time, it produced 442 metric tons of enriched lithium for nuclear weapons use. The NNSA says it has no current plans to enrich lithium.

The department has acknowledged that 907 tons of mercury used in enrichment operations were lost to the surrounding environment. A cleanup contractor, UCOR, has estimated that 109 tons of the toxic metal flowed directly from stormwater at Y-12 into an adjacent creek. Last November, DOE broke ground on stormwater treatment plants to mitigate further contamination, and \$17 million for those facilities is included in the FY 2018 omnibus appropriations act signed into law in March.

A further legacy of lithium enrichment is the more than 1200 tons of mercury stored in 35000 carbon steel flasks at Y-12. Public sales of mercury by DOE ended in 1993 because of environmental concerns. In 2007 a DOE estimate put a price tag of \$42 million on continued storage, environmental monitoring, and eventual repackaging of the mercury over the next 40 years.

Although ${}^6\text{Li}$ is preferred for weapons due to its higher energy content, ${}^7\text{Li}$ also will generate tritium in a secondary, as Los Alamos National Laboratory scientists learned to their surprise during the Castle Bravo nuclear test in the South Pacific in 1954. The largest US test, it was also the first to use ${}^6\text{LiD}$. Although somewhat enriched, the majority of the device's lithium content was ${}^7\text{Li}$. The 15-megaton explosion was more than two times the maximum predicted by designers, who wrongly assumed ${}^7\text{Li}$ to be inert. The 23 crew members of the Japanese fishing boat *Lucky Dragon 5* were exposed to the test's unexpectedly extensive radioactive fallout. One member died. The incident was an inspiration for the original Godzilla movie, *Gojira* (1954).

David Kramer 

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