Building cement 'prison' for old radioactive waste

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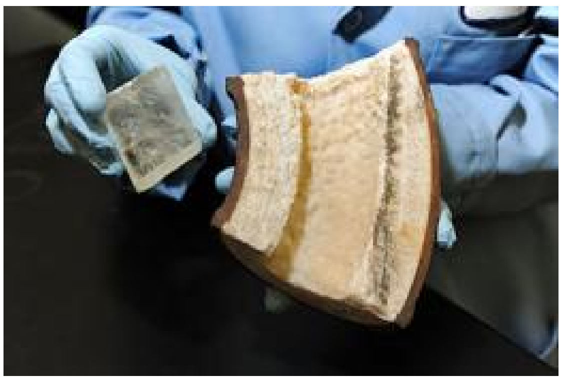


Bacteria and hard water can give heavy metals a hard time. Scientists coax underground microbes to turn calcium-rich water and urea into a stony underground trap for contaminants.

The Cold War ended long ago, but its radioactive legacy still lingers in the water and soil of the western United States. Between 1950 and 1990, nuclear weapons materials production and processing at several federal facilities generated billions of gallons of water contaminated with radioactive byproducts.

These sites have since updated their waste treatment practices to keep new contamination from entering the water supply. But some old contamination is still present.

Though public drinking water near Department of Energy sites in

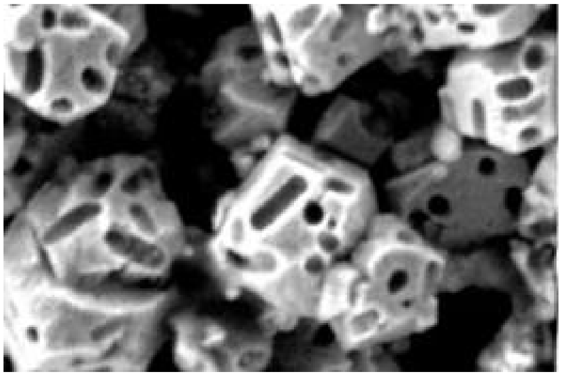
Washington and Idaho doesn't contain strontium-90 at concentrations above the EPA's safe drinking water limit, some monitoring wells at the sites do. At least some contamination in the monitoring wells is strontium-90 that slowly leached out of the soil.

"It's not something you want to leave to wash out," says James Henriksen, an INL microbiologist.

Researchers at Idaho National Laboratory, the Center for Advanced Energy Studies, and other national labs and universities are working together to test an inexpensive method to sequester strontium-90 where it lies. The researchers can coax underground microbes to form calcite, a white mineral form of calcium carbonate and the main ingredient in cement. And calcite should be able to trap strontium-90 until long after it has decayed into harmless zirconium. Strontium-90 has a nearly 30-year half-life, which means that a sample of the stuff will take around 300 years to decay more or less completely.

"Three hundred years is nothing for calcite," Henriksen says.

When people consume strontium-90 in contaminated food or drinking water, the radioactive isotope can replace some of the calcium in living bone. The bone-bound strontium-90 acts as a long-term source of damaging radiation that can spawn deadly cancers of blood, bone and skin.



A magnified view of microbially generated calcite crystals reveals pill-shaped impressions left by the microbes.

Cleaning strontium-90 out of the ground and water hasn't been easy. "There have been heroic efforts that cost enormous amounts of money," Henriksen says. Some of the most contaminated dirt was excavated, but digging up all the contamination would be astronomically expensive. And a project to pump out and treat contaminated groundwater only removed a tenth as much strontium-90 as did natural decay during the same period.

Pumping the groundwater wasn't effective because most of the contamination was stuck on solid surfaces underground, says INL environmental researcher Yoshiko Fujita. Remove the strontium-90 from the water, and more leaches off the solids to replace it.

So instead of trying to strip strontium-90 out of the ground, Fujita, Henriksen and their colleagues are trying to coax microbes to set a trap for it in the ground. The researchers are betting that the same chemical similarity that draws strontium-90 to bone will bind it into a microbe-made calcite "prison."

Doing hard time in a hard water prison

Calcium is an essential ingredient for calcite. Fortunately, there's no shortage of calcium in the ground at most sites with old radioactive contamination. Much of the groundwater in the arid American West contains so much dissolved calcium that crusty deposits of the mineral often clog water pipes near the DOE's Washington and Idaho sites.

Getting that calcium to turn into calcite on location and on demand requires molasses, urea and a little help from microbes. First, the microbes chow down on molasses and multiply, swelling their numbers by tenfold or more. A second course of urea, a cheap nitrogen fertilizer, prompts part of the expanded microbe population to generate calcite. They do so by using a protein called urease, to convert urea and water to carbonate and ammonium. The carbonate then joins with calcium in the ground and groundwater to form calcite.

Ammonium, on the other hand, performs the critical function of scrubbing strontium-90 ions off solid surfaces. The contaminant tends to cling to dirt and rock and resists efforts to extract it from soil. But ammonium, like strontium-90, carries a positive charge, which helps it boot strontium-90 off the surfaces of solids.

The research team has screened the Washington and Idaho sites to see if microbially generated calcite might offer a solution at contaminated sites in the West. Fujita and her colleagues describe the results of testing samples from the Washington site in a September 2010 paper in the journal Environmental Science & Technology . In addition to containing enough calcium and the right chemical conditions to support long-lived calcite formation, the water and soil at that site contained plenty of bacteria that could make urease and calcite — as many as several thousand such microbes in a drop of water or a gram of sediment.

Earlier studies of molasses and urea injections into the groundwater near INL showed that the microbes there will make calcite, too. Indeed, many places around the world contain all the ingredients to make microbial calcite. For example, urea and microbes have been used to make sustainable bricks from sand in Abu Dhabi, and have been proposed as a way to repair stone surfaces in Europe.

Clogged pipes and shifting streams

Before researchers can use the technique to clean up contamination in the ground, they need to show that they can control and predict microbial calcite formation. That's easy enough to do in a laboratory beaker, but reining in bacteria and chemical reactions in a complex underground environment has posed many practical and scientific challenges.

For instance, in one of their first field experiments, Fujita and her colleagues generated so much calcite that they clogged their injection well and burned out a pump. "What a success!" Fujita recalls collaborator and University of Idaho geochemist Robert Smith saying upon hearing the news. "He was only half-joking," Fujita says. The clog made it difficult for the researchers to measure how much calcite they'd made or how much bacterial growth they'd stimulated.

For their next set of field experiments, the team upgraded to multiple wells and moved to the Vadose Zone Research Park at the INL desert Site. Having more than one well meant they could create their own water flow and study how far they could get the injected urea to go. But they had trouble getting the urea and molasses injections to go the way they wanted.

Henriksen describes the problem by sketching an underground stream taking a tortuous route through hidden gravel pits and around impermeable layers of basalt and clay before finally draining into the Snake River Plain Aquifer. "It's really complicated and dynamic," Henriksen says. "You can't just reach down there and make the water go where you want."

In addition, the amount and rates of water moving through the ground at the park can change. Fujita and colleagues spent their first year at the research park studying underground water movement. The team showed up the next year with many carefully planned experiments, only to find that the park water conditions had drastically changed. One well was even completely dry. The experiments had to be scrapped.

But Fujita, Smith, and Henriksen haven't yet given up on microbial calcite. They took care to locate their latest experiment at a well-studied DOE research site at an old uranium ore processing facility in Rifle, Colo. Henriksen and his colleagues are evaluating the effect of their molasses and urea injections on the local microbe community and working with hydrologists to help them understand Rifle's underground water dynamics. The INL researchers couldn't dig up enough of the ground to look directly at how much calcite they'd generated and where, so they enlisted geophysicists to help them detect those things remotely with ground radar and by measuring any effects the underground reactions might have had on the ground's capacity to conduct electric current.

The forthcoming results of the Rifle experiment should get INL researchers closer to being able to predict the results of future efforts to stimulate microbial calcite formation. The researchers would like to expand their knowledge of the process with more and larger scale tests at contaminated locations, such as a pilot study at the Washington site, Fujita says.

Despite the frustration of thwarted experiments, Henriksen remains enchanted by the complexity of studying and manipulating microbes in the environment.

"Most people don't think about the bacteria everywhere around them or about utilizing the amazing capabilities bacteria have," Henriksen says. "They can do a lot of things we can't. Now we have the tools to work with them."

Provided by Idaho National Laboratory

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