RETHINKING NUCLEAR WASTE

NEW nuclear reactor designs

and the new fuels they will require could mean the end of nuclear waste as we now think of it.

By Gene Charleton

A growing number of energy experts and even environmentalists are calling for wider use of nuclear energy to reduce our dependence on oil and other fossil fuels without contributing to global climate change. Critics ask, "But what will we do with the radioactive waste?"

Nuclear engineer Sean McDeavitt thinks that's the wrong question.

"Most people live at the 'What are you going to do with the waste?' question," says McDeavitt, an assistant professor and specialist in reactor fuels and nuclear materials in Texas A&M's Department of Nuclear Engineering. "They're already assuming a certain path with that. It presupposes that used fuel is all waste that we're going to figure out how to deal with. This also assumes that the solution is a vast mystery that no one understands."

But new designs for advanced nuclear reactors and the fuel that powers them could make nuclear waste as we now think of it a thing of the past, he says.

"It all comes down to the presuppositions," he says. "If you restructure your design philosophy forward, you can manage the majority of the long-lived waste out of the picture, to a certain extent."

Fission 101

Most of us understand at least the outline of how atomic fission works: A neutron zaps into a pile of uranium atoms and splits one. Fragments from that split atom ("nuclear shrapnel," McDeavitt calls them) include newly liberated neutrons that zip out and in turn split other atoms, and so on. As this splitting, or fission, continues, it produces energy, which we see as the heat that turns water into steam that turns turbines to give us electricity.

"Nuclear energy is a fancy way to boil water," McDeavitt says. "If you've got coal, you can boil water the old-fashioned way."

> "The vision would be to develop a reactor that does not require fuel enrichment and that does not require reprocessing. Take away these major proliferation risks and 'nuclear' becomes not so dirty a word."

The atoms in that pile are uranium atoms, but uranium is only the beginning, especially for the sort of advanced reactors McDeavitt is talking about. The fuel used in most commercial reactors starts as a metal ore containing uranium, abbreviated as U. Most reactors use uranium dioxide, or UO_2, a combination of uranium and oxygen, although some fuels are alloys of uranium and other metals. Fuels also can be made by combining uranium with nitrogen, silicon, carbon or hydrogen.

"You can make fuels out of nitrides or carbides or silicides or hydrides or essentially any kind of chemistry that will hold the uranium in a solid form and get it into the system," McDeavitt says.

Other fuel variations can be fabricated, but most often they're reserved for niche applications, usually in research reactors. The main function of the fuel is to get the uranium into the presence of the neutrons that cause them to split apart. Fuel design aims to fine-tune that fission process, depending on exactly what engineers want to have happen during fission and afterward.

Whenever nuclear fission takes place, the splitting of the uranium atoms results in chemical changes in the fuel involved. After a while, those changes produce elements quite different from the uranium we started with.

"You almost have the entire periodic table by the time you're done," McDeavitt says.

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Future reactors

New reactors envisioned by nuclear engineers range from what nuclear energy specialists call Generation 4 reactors, essentially improved, safer, more fuel-efficient versions of the reactors we use today, to even more advanced designs such as what's known as a traveling-wave reactor that TerraPower is designing. McDeavitt's research focuses on the fuel these advanced reactors will use rather than on the design of the reactors themselves.

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One way to visualize how a traveling-wave reactor works is to imagine the reactor as a line, rod or stick with a wave moving along it. The wave is the nuclear reaction, and it moves slowly (a few centimeters per year) along the fuel in the reactor as the fuel is changed by the continuing reaction. A similar reactor that engineers in Japan are studying is called a candle reactor, because the fuel is "lit" at one end and "burns" to the other end like a flame on a horizontal candle.

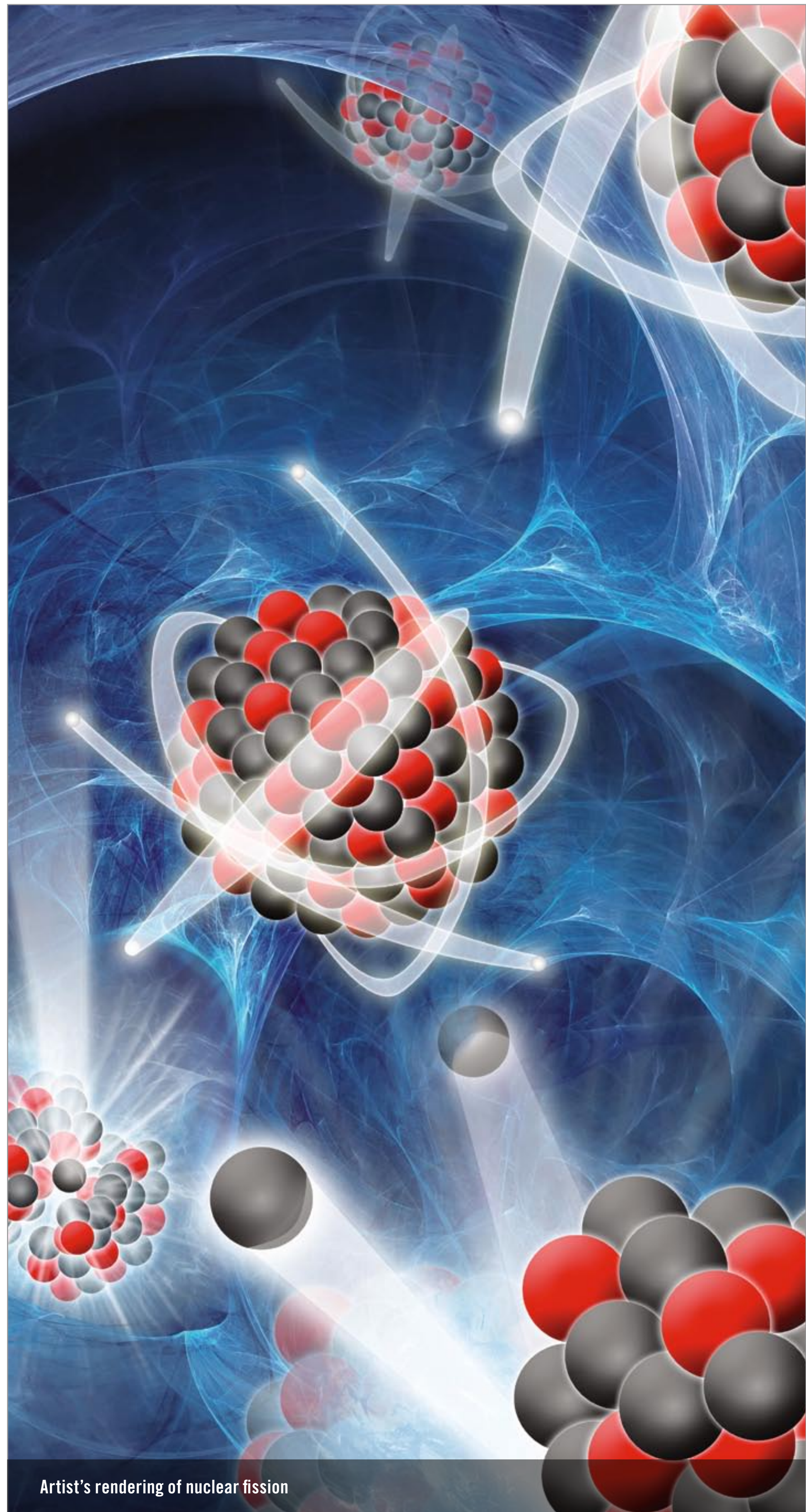
Unlike conventional reactors, in which fuel is replaced every three to four years, the fuel in traveling-wave reactors could be in place for 40 to 50 years, and the residue left when the reaction has traveled through all the fuel could be used to fuel other reactors rather than being reprocessed or stored.

"The vision would be to develop a reactor that does not require fuel enrichment and that does not require reprocessing," McDeavitt says. "Take away these major proliferation risks and 'nuclear' becomes not so dirty a word around the society."

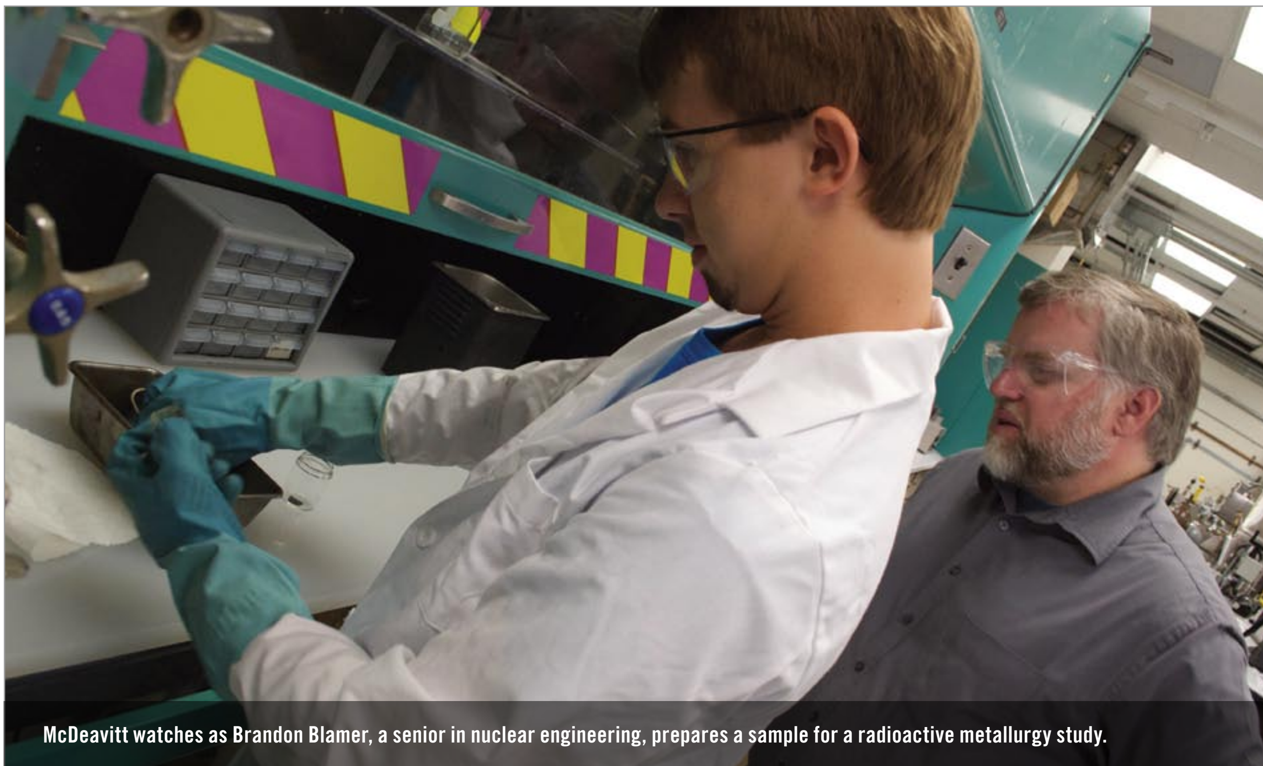
The future of fuel

Another project from McDeavitt's current research is concentrated on a potential new fuel that may be used in current-generation reactor systems. This new fuel form was invented at Purdue University, and McDeavitt is now working with IBC Advanced Alloys of Vancouver, Canada, to establish engineering-scale fabrication methods. The fuel combines uranium dioxide and beryllium oxide to produce higher thermal conductivity in the fuel. Developing it is a cross between materials science and manufacturing methods, he says.

"We're down to engineering the morphology, the form and structure, of the fuel material," he says.



Artist's rendering of nuclear fission



McDeavitt watches as Brandon Blamer, a senior in nuclear engineering, prepares a sample for a radioactive metallurgy study.

The goal is to develop a combination of uranium dioxide and beryllium oxide particles that when combined into fuel pellets, allows reactors using it to operate more efficiently than with current fuels.

Essentially, the fuel fabrication method starts with a powder made up of tiny balls of uranium dioxide about 500 microns, or half a millimeter, in diameter and smaller bits of beryllium oxide. These particles are pressed and then sintered, or heated and pressed together, into pellets that go into tubes that make up the reactor core. Understanding the structure of the fuel material is crucial, because a homogeneous mixture behaves differently from a heterogeneous mixture, and heterogeneous mixtures' behavior can be different, depending on how the ingredients are combined.

It's complicated. For instance, if you sinter and press the fuel in an oxygen atmosphere (such as air), the uranium becomes U_3O_8. If it's done in an argon or argon–hydrogen atmosphere, it will be maintained as UO_2.

"With engineering, everything has issues. That's what I tell my students," McDeavitt says. "You just have to choose which issues to overcome and make the system work.

"So when people ask, 'What are you going to do about the waste?' they've already assumed you have to do something with the waste. That's already assuming it is waste and not another raw material.

"I like to assume it is a useful raw material." ✯

Nuclear Engineering at Texas A&M

Texas A&M has one of the largest and best nuclear engineering programs in the country. It is widely recognized as one of the best-equipped nuclear engineering programs, with two nuclear reactors: a 1-megawatt TRIGA reactor for research and a 5-watt AGN reactor for teaching. The Nuclear Science Center provides an excellent teaching facility for students; produces medical isotopes and membranes for kidney dialysis; and contributes to research and testing support for the university and industry.