

Need for clean energy, waste transmutation revives interest in hybrid fusion-fission reactors

Sweet solution or pie in the sky? Hybrids get new attention.

Fusion-fission hybrids, in which fusion acts as a neutron source for a fission reactor, would not only produce power but also burn nuclear waste and could produce fissile fuel. That's what attracts proponents, but skeptics worry that the complications and costs of combining the two technologies outweigh the benefits.

The idea of fusion-fission hybrids has been around for decades. (See the article by Hans Bethe, *PHYSICS TODAY*, May 1979, page 44.) Its renewed traction—as evidenced by a conference in May organized by New York University and the nonprofit Brookings Institution, a workshop this fall sponsored by the US Department of Energy (DOE), and several independent designs—is thanks to the growing urgency of generating power free of carbon emissions.

Currently, some 100 nuclear reactors

supply about 20% of electricity in the US. If the push to increase that fraction is successful, the pressure to deal with the attendant waste will grow. "What's really rejuvenated interest in hybrids is the emphasis on the environment," says Jeffrey Freidberg, associate director of MIT's Plasma Science and Fusion Center and chair of the DOE workshop. "The question arises, What will we do with the waste?" With its May budget request (see page 29), the Obama administration proposes to kill the long-controversial Yucca Mountain site for waste burial. The administration also announced that a blue-ribbon panel will consider options for disposing of civilian nuclear waste.

Moreover, the planet's uranium supply is limited. It could be stretched out by fusion-fission hybrids, as well as by fission breeder reactors. "There was a time when hybrids were a no-no, because fission was unpopular," says Steven Cowley, director of the UK's fusion program. "I think it's time we study these systems again."

In the US, three hybrid designs stand out. Two use magnetic fusion. The third, at Lawrence Livermore National Laboratory, uses inertial confinement fusion, build-

ing on the work at the lab's National Ignition Facility (NIF).

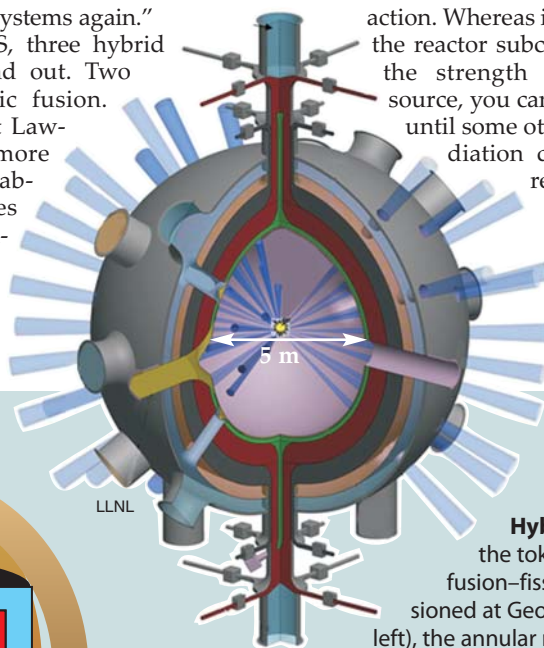
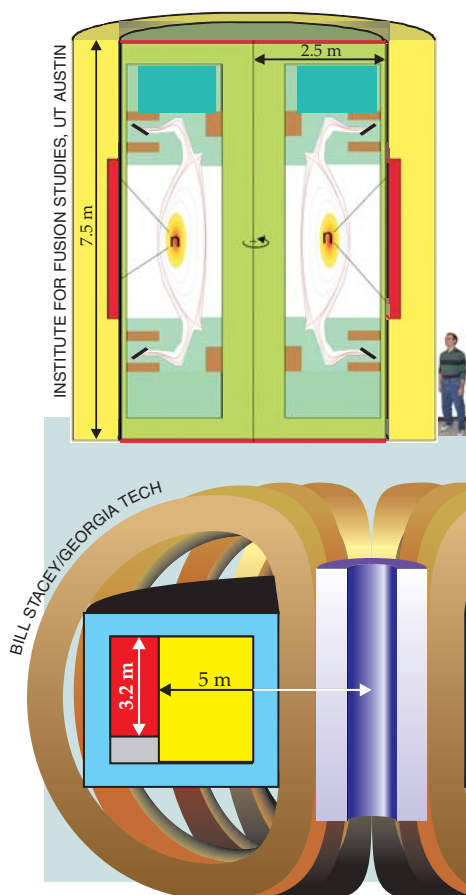
Servant to fission

In a hybrid, neutrons from fusion would enter a "blanket" of fissile material and either induce fission or be captured. The fission energy released could be converted into electrical energy, as in any fission reactor.

But a hybrid's most important function is consuming nuclear waste, says Swadesh Mahajan of the Institute for Fusion Studies at the University of Texas at Austin. "With all humility, fusion is saying [to fission], 'We will become your servants and help you gain social acceptability by destroying the toxic waste you create in the act of energy production.'"

"In a critical transmutation reactor," says Bill Stacey, who heads a hybrid design project at Georgia Tech, "you don't have enough neutrons after awhile to maintain the fission chain reaction. Whereas if you can operate the reactor subcritical and adjust the strength of the neutron source, you can leave the fuel in until some other limit—the radiation damage limit—is reached."

Leaving the fuel in longer, he adds, means his hybrid would



Hybrid designs. In the tokamak-based fusion-fission design envisioned at Georgia Tech (lower left), the annular reactor core, or fission blanket (red), is inside the tokamak magnets (brown) surrounding the plasma (yellow). The University of Texas's design (upper left) would use a spherical torus and has the fission blanket (red) outside the magnets. In Lawrence Livermore National Laboratory's hybrid (above), fusion is created by firing lasers (blue) at a hydrogen fuel pellet (yellow). The resulting neutrons would cause fission in the reactor blanket (dark red).

burn 25% of the transuranics before the fuel had to be replaced, compared with about 5% in a critical fission reactor. The fuel would then be reprocessed and reused. "You have to repeat this reprocessing six or seven times to get to about 95% burn up," says Stacey. Erik Storm, who heads Livermore's hybrid effort, says the lab has developed a once-through, closed nuclear cycle for its hybrid design. "If we wanted to burn the transuranics in spent fuel," he says, "we would have to reprocess, but we would then burn it to 99.9% burn up in a single step, without the need for further reprocessing." At those levels of burn up, says Stacey, "you've done something significant" to reduce the amount of waste that has to go into long-term storage.

The question is, Stacey says, "Are those big advantages worth the extra cost? Hybrids will definitely be more expensive [than fission reactors]." But, he adds, "if you start looking at the cost of disposing of transuranics, it might actually be cheaper. No one has really done this larger cost calculation."

No hybrid has yet been made, and many questions remain about pursuing them versus pure fusion reactors (for power) and fission breeder reactors (for power, fuel production, and waste transmutation). Says Ed Moses, Livermore's associate director in charge of NIF, "There is nothing wrong with the physics. But there are technology questions, and what about the economics? Once you get past that, how fast could we do it?"

Magnetic-fusion hybrids

Stacey's design would use a scaled-down version of ITER, the international fusion reactor under construction in France, and a sodium-cooled fast fission reactor. The blanket would be inside the tokamak (see figure on page 24). "We've taken the most developed fast-reactor concept and the most advanced magnetic-fusion concept. If we are going to try this, let's try it with the best we've got," says Stacey. He and his team have been working on the design for a decade, and, he says, "We've probably done more calculations than anyone else."

The demands on the plasma physics for a hybrid are less rigorous than for electrical power production with pure fusion. For example, says Stacey, "the plasma pressure doesn't have to be as high, and confinement doesn't have to be as good." But a hybrid would still need to use a deuterium-tritium reactor to get enough neutrons, and for that, ITER is the only game around. ITER can't compete economically for producing power, Stacey says, "but the param-

eters it will achieve are perfectly fine for a neutron source. And in a hybrid, fission is doing most of the job."

The other magnetic-fusion-based hybrid design puts the fission blanket outside the magnetic field (see figure, upper left). It would use a spherical torus rather than a tokamak and, for the fission part, reprocessed spent fuel from light water reactors. "We have a much more compact and high-density design for our fusion neutron source," says Mahajan, part of the UT team that is spearheading the design, which recently gained participants from a couple of national labs. "The power density is roughly five times as high as in the other designs. This is an engineering distinction with a large ramification."

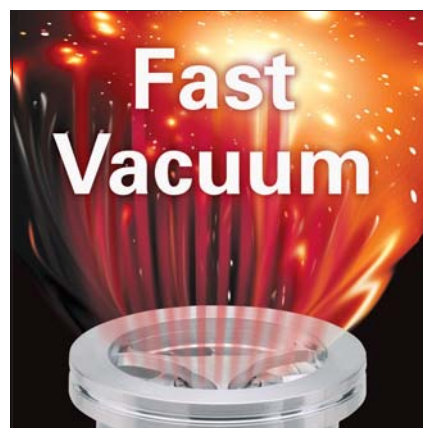
Because of its compactness, the fusion portion of the UT hybrid can be replaced every year or two, so the machine's materials do not have to withstand as much neutron bombardment. "This also reduces the time we have to spend on testing materials," Mahajan says. "[Another advantage] we bring over fast reactor systems is that the plutonium is burned in the light water reactor. It does not circulate through the hybrid system. The proliferation risks are greatly reduced."

"But most important," he says, "our design will have a support ratio of 15 to 25." That's the number of light water reactors whose waste the UT hybrid could handle. By contrast, Mahajan adds, the support ratio of breeder reactors is three or four. Hybrids have a "tremendous economic advantage," he says, "when we choose a fuel cycle that can exploit to the hilt the subcritical hybrid's ability to burn the most toxic fuel, including most transuranics."

New LIFE for NIF?

With the biggest publicity machine behind it, the design that is generating the most buzz is Livermore's Laser Inertial Fusion Engine. LIFE would adapt and exploit NIF science by directing neutrons from inertial confinement fusion into a fission blanket (see figure, right). NIF was dedicated on 29 May, and a campaign for ignition—creating fusion by firing the facility's 192 lasers at a tiny hydrogen fuel pellet—is set to begin this fall. "The fact that ICF burn is a point source of neutrons is extremely important in making [LIFE] work," says Moses. "There is no place for the neutrons to escape, so we use all the neutrons. That's a really big deal."

The magnetic-fusion-based hybrid designs would use reprocessed fuel, in which transuranics are separated from fission products, leaving a higher density



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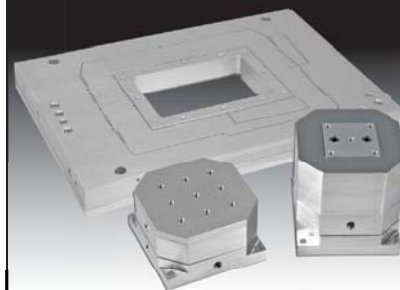
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of toxic elements to be burnt up and less stuff that just absorbs neutrons. But Livermore says LIFE could burn any sort of fuel—uranium, plutonium, spent fuel, reprocessed or not. “It’s really a fusion engine,” says Storm. “It can run in pure fusion mode, or a utility or the government decides what type of fission blanket to put around it.”

Any of the hybrid designs would generate about 1 GW of electricity. And by burning transuranics, any of the designs would effectively close the fuel cycle and thus shrink the volume of long-lived waste that requires long-term storage.

Hybrid hurdles

Still, many scientists say Livermore is jumping the gun—that before touting LIFE, it should prove that NIF can achieve ignition. “I would have thought more modesty was in order until they had actually demonstrated that they can make the little pellet go bang,” says Burton Richter, the former SLAC director who consults for Livermore on creating a NIF user program.

Even once the pellet does go bang, LIFE faces technical, political, and financial hurdles. “They need to develop an entirely new kind of laser,” Richter says. LIFE would have to fire 10–20 times a second, whereas NIF will fire just several times a day. The ignition chamber has to be cleared of debris and a new pellet has to be automatically dropped in at the firing frequency. Once those problems are solved, he says, “you can worry about the rest of the problems, such as having a first wall that can handle the big neutron flux.” But, he adds, “should they be able to make the pellet go bang, then I think it’s potentially interesting enough to look at the next step—the higher rep rate laser and the automated pellet factory.”

Several fusion scientists told PHYSICS TODAY that they couldn’t assess LIFE because Livermore was keeping details close to the vest. Some are more skeptical: Roald Sagdeev of the University of Maryland at College Park calls LIFE “science fiction, at least until ignition is demonstrated. I am not an engineer, but many of my friends think [the challenges of LIFE] are insurmountable.” And many suspect that Livermore is so hot on LIFE because it wants a new raison d’être—a new big project bringing in billions of dollars once NIF becomes a tool. They also say that Livermore’s aim of having a demonstration hybrid engine by 2022 is unrealistic.

But Storm says that what keeps him awake at night is neither the technical aspects of LIFE nor the aggressive time-

Lunar spaceflight history on the block

On 16 July, 40 years to the week after the first manned Moon landing on 20 July 1969, lunar spaceflight memorabilia are being offered at auction in New York City by Bonhams New York. The auction includes artifacts from all the Apollo manned missions.

Among the roughly 400 items on offer will be a lunar dust brush, scale models of spacecraft by engineer Maxime Faget, checklists, and “insurance” postal covers. A letter (also in the sale) from Buzz Aldrin explains that he and the two other *Apollo 11* astronauts signed the postal covers, which were postmarked the day of launch; the idea was for their families to sell them if the mission ended in disaster.

One item that Bonhams expects to fetch as much as \$300 000 is a flight vehicle attitude hand controller assembly (see photo) from the *Apollo 15* lunar module. Lunar modules were not designed to return to Earth, so the controller assembly is rare.

A star chart on the block, says Gregg Linebaugh, a consultant who was instrumental in putting together the auction, was used by the *Apollo 11* crew to figure out where on the Moon’s surface they had landed. “The star chart represents a tie from sailing vessels. Using something like that on the Moon’s surface is amazing,” Linebaugh says.

Most of the items came directly from astronauts or private collectors. Until the mid-1980s, Linebaugh says, the dispersal of artifacts “was a gray area. NASA retained the vast majority of the hardware, but at the paper level, the astronauts got to keep things. The shuttle crews are no longer allowed to keep much. They can keep their personal kits and some mementos.” This sale, he adds, “is probably the last big chance to see such a broad variety of extremely historical and important items from the early space program.”

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line, but rather “the chance of getting money to do this. The political will. With a Manhattan Project-like effort, we could have a demonstration machine in 10 to 12 years.” The project, he adds, “needs something like the Einstein letter [to President Franklin D. Roosevelt in 1942 in support of developing an atomic bomb]. It needs [President] Obama to come out in favor when NIF gets ignition.”

The magnetic-fusion-based hybrids also face technical hurdles. In the case of the tokamak design, ITER is still nearly a decade from completion. And no spherical tokamak currently exists to test and develop the UT design.

Fuel reprocessing is a limiting factor for the two magnetic designs. “We’re probably 10–15 years before that is technically ready to go,” says Stacey. Reprocessing is not currently done in the US, and MIT’s Freidberg sees that as a significant obstacle: “Our government can’t decide if plutonium is our friend or foe.”

Another issue is that hybrids don’t have a home in any federal agency. “The fusion department of DOE doesn’t

do fission, and the fission department of DOE doesn’t do fusion,” says UT’s Mike Kotschenreuther. “So hybrids fall through the cracks.”

Community discussion

Still, hybrids are gaining interest in the US and other countries. “One thing I’ve wondered about is, Where does the sweet spot lie?” says the UK’s Cowley. “How much fusion? And how much fission? If you have a pretty good fusion system, then why bother introducing extra complications—uranium, reprocessing, hazardous materials? If you can do pure fusion, there is no reason to [develop hybrids], not for energy anyway. But pure fusion is harder. How much harder? These are the kinds of questions the field has to address.”

Another question is price. “The cost of reprocessing and transmutation is enormous no matter what the source of neutrons. If you throw enough money at any technology, you might get it to work, but the sky is not the limit,” says Edwin Lyman, a senior staff scientist with the global security program at the

Union of Concerned Scientists. "Going to more complex nuclear systems to get out of the climate change problem is not the best direction."

Citing a comment by Livermore that twice as much laser input would be needed to get 3 GW from inertial confinement fusion than from fission, Richard Garwin, a long-time adviser to presidents on nuclear weapons and energy issues, says, "I'd rather do the research for fusion than a hybrid." The hybrid, he adds, "tries to be all things to all people. I am a big supporter of breeder reactors. You are going to need repositories anyway for fission products. I believe that hybrids combine the worst of fusion and fission."

Many scientists do agree, though, that it's worth scrutinizing hybrids and debating their merits. MIT's Freidberg notes that while hybrids "were not treated too seriously within the fission community in the past," that may be changing. But, he adds, "I'm glad we don't need them urgently, because I don't think we can deliver urgently."

Toni Feder

Votano named director of underground lab

In September, Lucia Votano becomes director of Italy's Gran Sasso National Laboratory, the world's largest underground laboratory. She is the first woman to hold the post. Her predecessor, Eugenio Coccia, plans to return to research in astroparticle physics and teaching after two three-year stints at the lab's helm.

Since 1985 when Votano came to Gran Sasso, she has worked on two experiments and also served in management roles, most recently as chair of the OPERA (oscillation project with emulsion-tracking apparatus) collaboration, which studies neutrino oscillation using a beam from CERN.

One challenge facing Votano will be dealing with the aftermath of the magnitude 6.3 earthquake of last April. Gran Sasso escaped damage, but the area was hit hard, with more than half of the lab's staff rendered homeless and the nearby University of L'Aquila devastated. Those who lost their homes have been staying in nearby hotels or with relatives, and in June some moved into temporary housing on the lab's grounds. The lab is helping people find and pay for such housing and for travel to the lab. Gran Sasso also opened its doors to the university, which is hold-

ing physics classes there. "This operation to have lectures in a research center is quite rewarding," says Coccia. "More students are attending than when the lectures are at the university."

Since the area is unlikely to have recovered from the earthquake by September, Votano says, "I have to continue the effective job of the present director." So effective, she adds, "that less than one month after the earthquake, all the experiments were fully operative."

Gran Sasso hosts more than a dozen international experiments, devoted mainly to investigating neutrinos and dark matter. "The role of Gran Sasso in astroparticle physics is quite relevant," says Votano. "We have experiments that address the fundamental questions. My challenge will be to preserve and improve this rich legacy."

Votano took the top job because, she says, "I feel I can do something for the lab. Due to my long experience there, I feel fairly aware of the needs of the lab. I can promote physics and at the same time support the people working there."

Toni Feder



Votano

Kirby to become executive officer of APS

On 13 July, Kate Kirby, a physicist at the Smithsonian Astrophysical Observatory (SAO) and a senior research fellow and lecturer in Harvard University's astronomy department, will succeed Judy Franz as executive officer of the American Physical Society. Franz is retiring after 15 years in the post.

"APS is an exciting and dynamic organization that both involves and serves the community very effectively," says Kirby. "It does a lot of wonderful things for physics and the physics community."

"I've been involved with the society for more than 25 years," she adds, "and



Kirby